Pion-proton femtoscopy at RHIC

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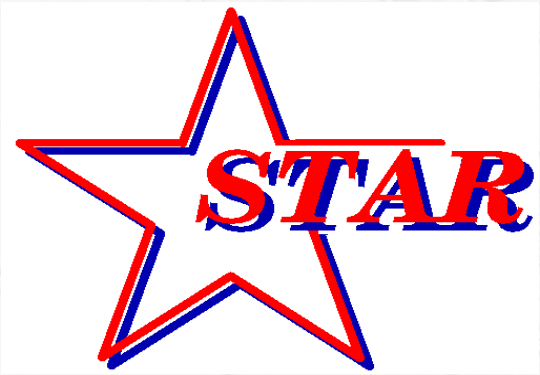
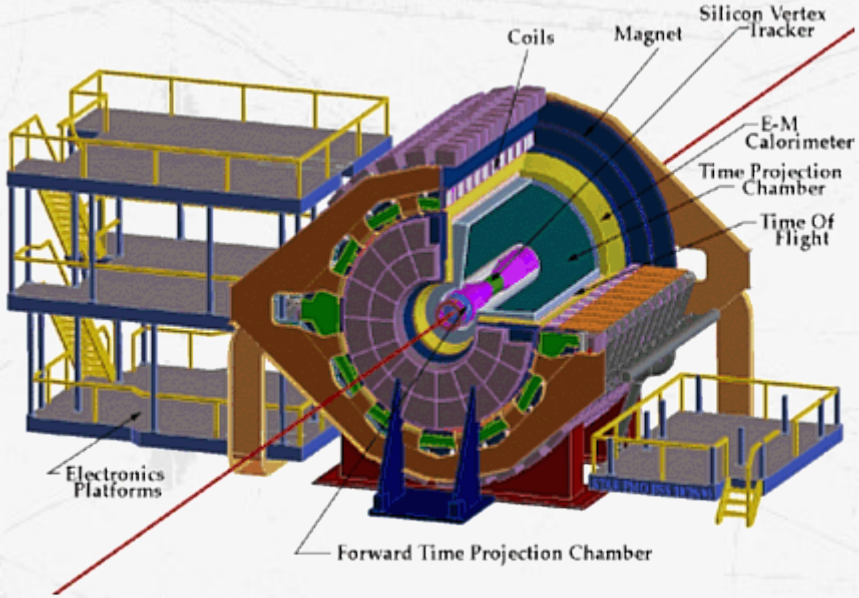
Hot Quarks 2010

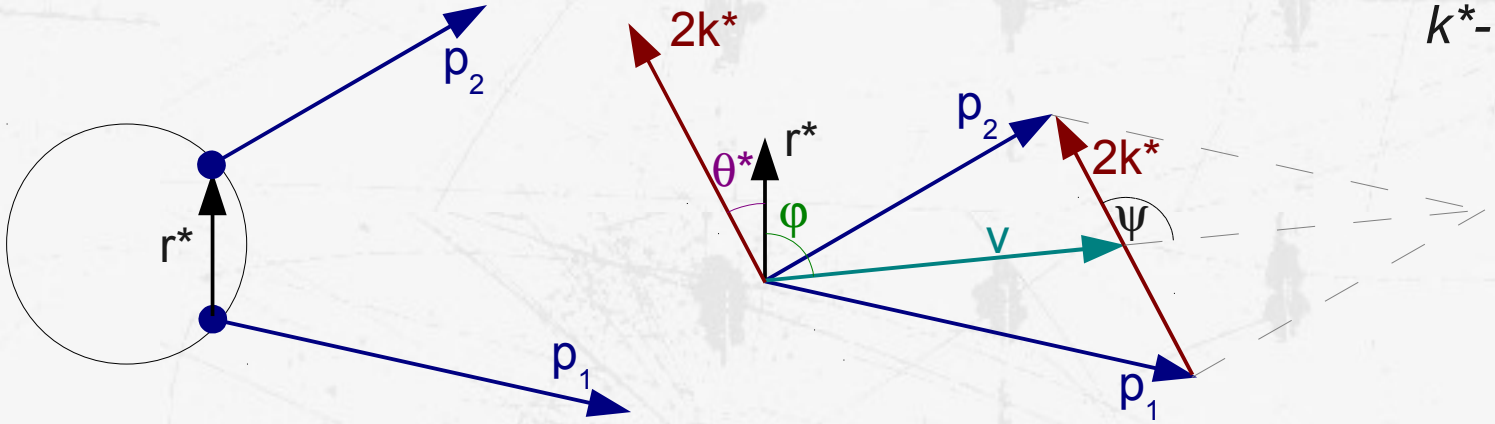


Outline

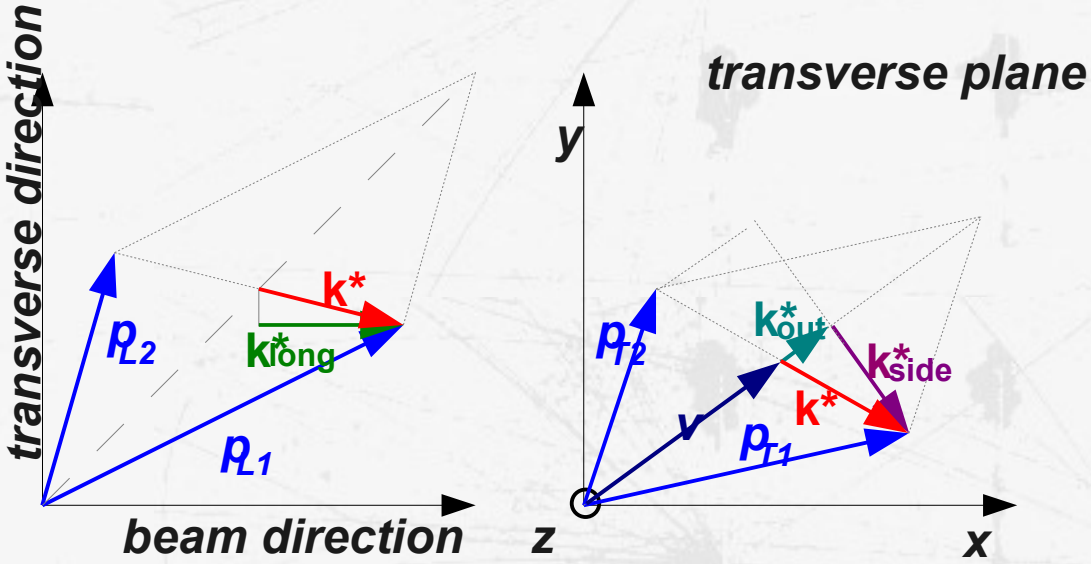
- Physics motivation
  - size and asymmetry measurement
- Data analysis
  - data selection
  - purity correction
- Experimental results
  - correlation functions
  - fit results
- Model results
- Pion & proton HBT
- Conclusions



Construction of experimental correlation function



*k**- momentum of the first particle in PRF (Pair Rest Frame), half of the relative momentum



k* distribution of **correlated** pairs coming from the same event

$$C(k^*) = \frac{N(k^*)}{D(k^*)}$$

k* distribution of **uncorrelated** pairs particles coming from different events

FSI as an origin of asymmetry

$$CF = A_C(k^*)\left[1 + 2\underbrace{\langle r^*(1+\cos\theta^*)\rangle}_{\text{integrated over space}} / a_c + \ldots\right]$$

Gamov factor

Source of the asymmetry

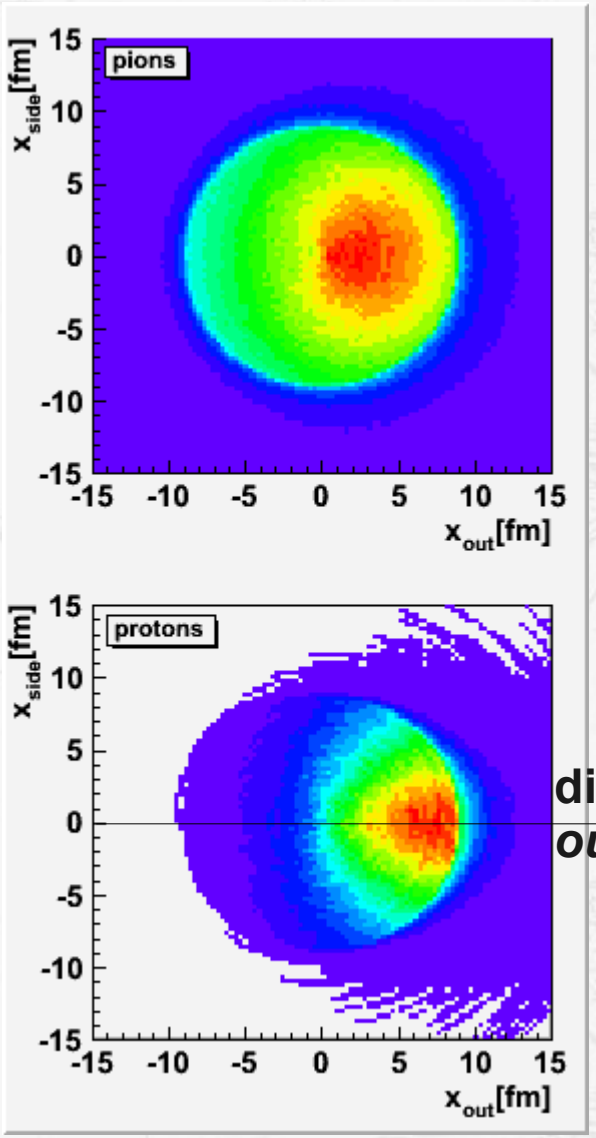
Bohr radius for $\pi-p$ $a_c = \pm 222$fm

In pion-proton system only coulomb interaction plays significant role.

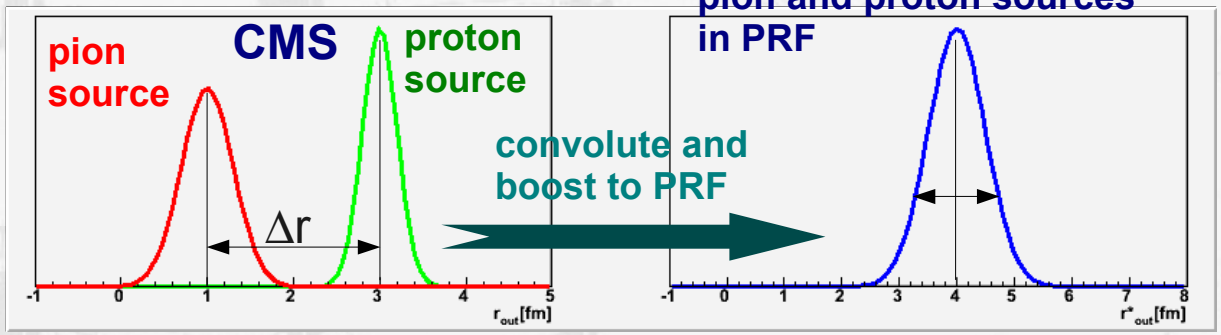
k- momentum of the first particle in PRF*
r - separation between emission points*
θ - angle between **k*** and **r*** vectors*

Correlation is stronger when *cosθ*<0* – *k and *r** are anti-aligned and weaker when *cosθ*>0* – *k** and *r** are aligned.**

Observed asymmetry



direction of a pair
out



$$\sigma_{\pi p} = \sqrt{\sigma_\pi^2 + \sigma_p^2}$$

two particle width

single particle widths

Observed separation in PRF comes from

- **space asymmetry (flow)**

and from

- **emission time difference**

$$\langle r^* \rangle = \langle \gamma_T (\Delta r - \beta_T \Delta t) \rangle$$

Phys.Lett.B373 (1996) 30

Decomposition and interpretation of the correlation function in spherical harmonics

distribution of correlated pairs

distribution of uncorrelated pairs

$$T(\vec{k}^*) = C(\vec{k}^*) \cdot M(\vec{k}^*)$$

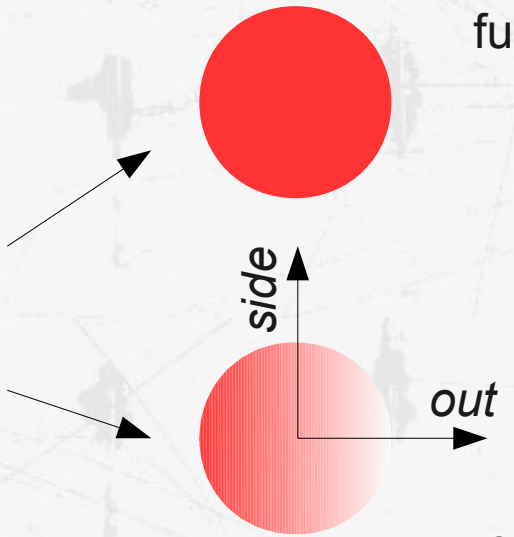
correlation function

$$C(\vec{k}^*) = \sqrt{4\pi} \sum_{l,m} C_{lm}(\vec{k}^*) \cdot Y_{lm}(\theta, \phi)$$

Symmetry:

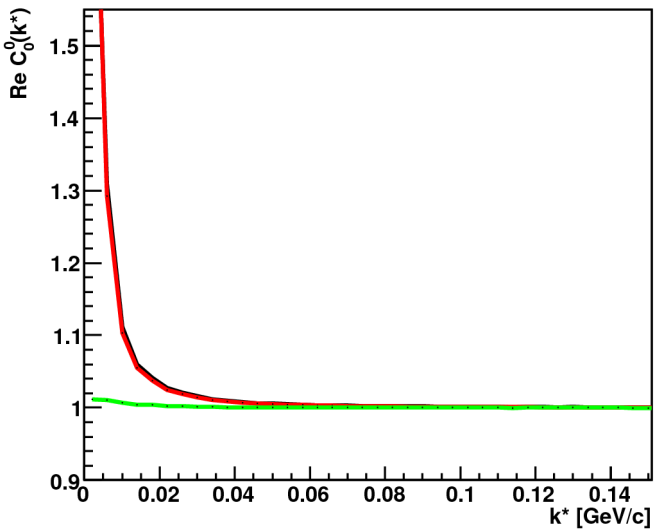
- Calculated function is integrated over reaction plane angle thus all imaginary elements vanish.
- Symmetric mid-rapidity region → odd (*l*+*m*) real components of the function vanish

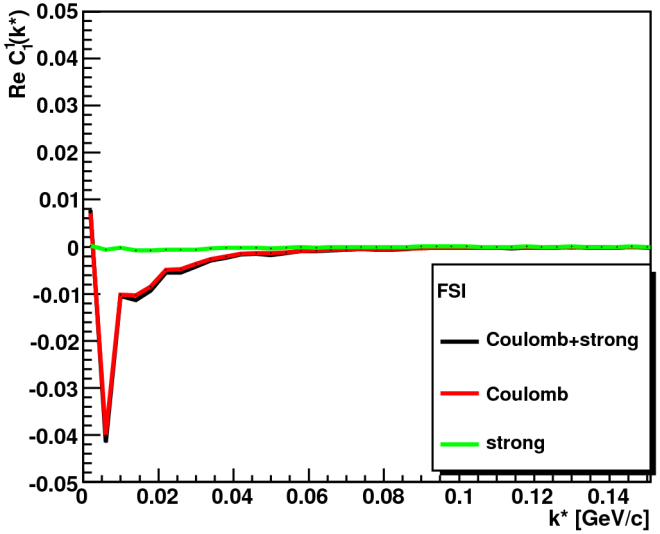
- **C^0_0 functions give information about overall size**
- **Re C^1_1 component gives information about asymmetry.**

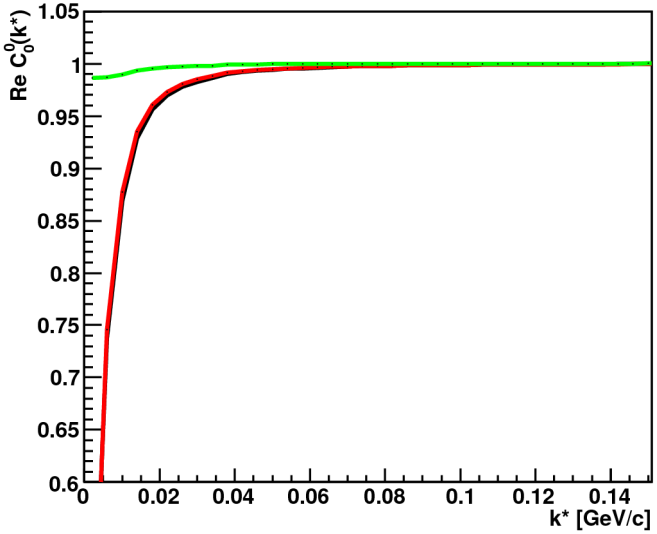


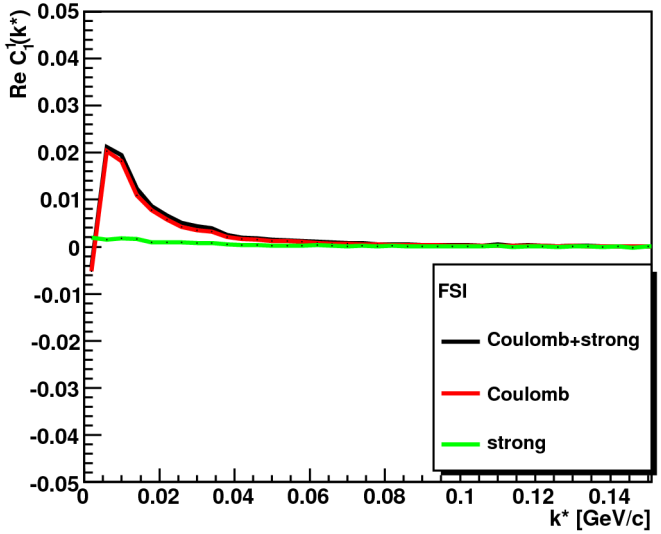
Z.Chajęcki, M.Lisa; Phys.Rev.C78:064903,2008
A. Kisiel, D.Brown; Phys.Rev.C80:064911,2009

Final State Interaction in pion-proton system







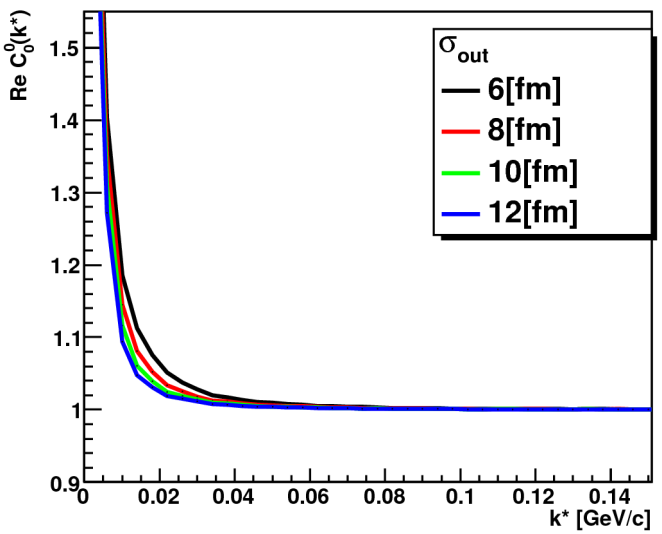


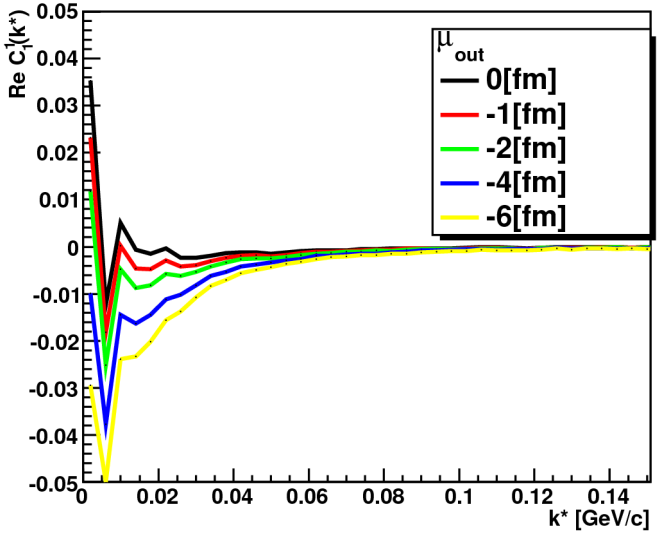
Final State Interaction in pion-proton pairs is dominated by Coulomb interaction (red line), strong interaction (green line) is negligible.

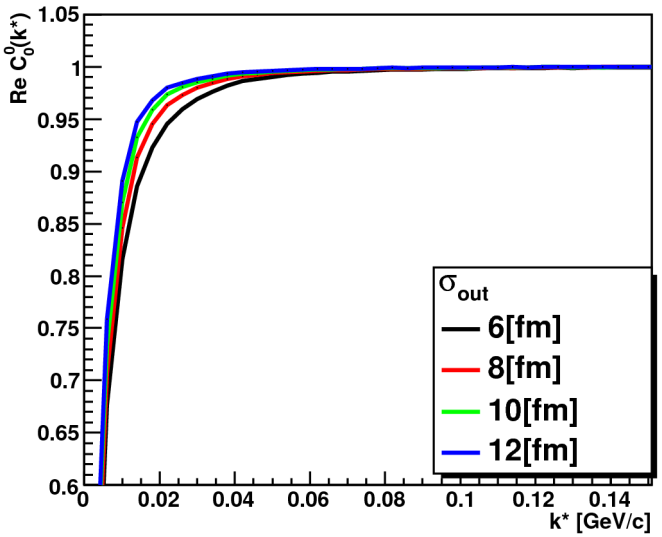
Coulomb interaction for like-sign pairs is repulsive thus correlation effect is negative. For unlike-sign pairs Coulomb interaction is attractive thus observed correlation effect is positive.

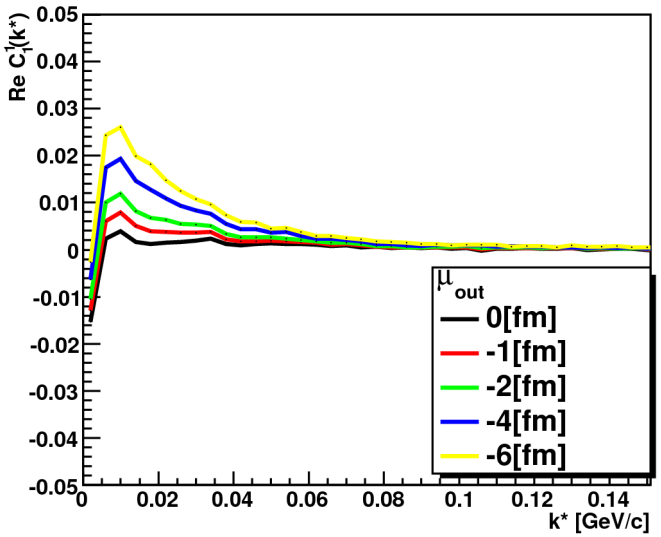
R. Lednicky et al, Phys. Lett. B 373, 30 (1996).
A.Kisiel, Nukleonika 49 s81-s93 (2004)

Dependence of pion-proton correlation function on size and asymmetry of the source









Smaller size gives stronger correlation effect in real part of the C00 component of the correlation function.

Bigger asymmetry gives stronger effect in real part of the C11 component of the correlation function.

R. Lednicky et al, Phys. Lett. B 373, 30 (1996).
A.Kisiel, Nukleonika 49 s81-s93 (2004)

Data selection

Au+Au $\sqrt{s_{NN}}$ =200GeV

Events:

- central (0-10%)
- semi-central (10-30%)
- mid-central (30-50%)
- z-vertex position ±30cm

Single track level cuts (π,p)

- dE/dx
- $p_T(\pi) \in <0.1,0.6>$
- $p_T(p) \in <0.4,1.25>$
- $y \in <-0.7,0.7>$

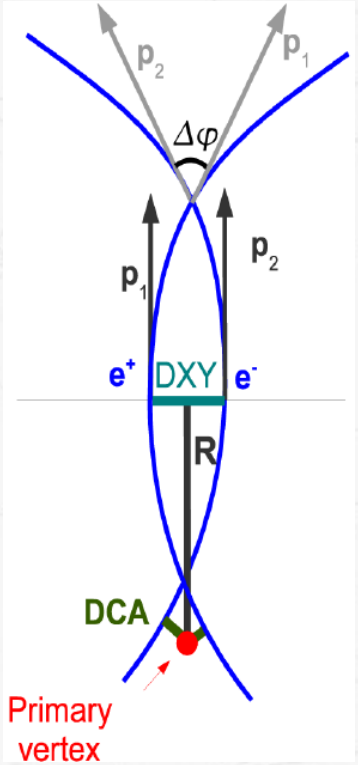
Pair level cuts:

pairs with merged hits of tracks

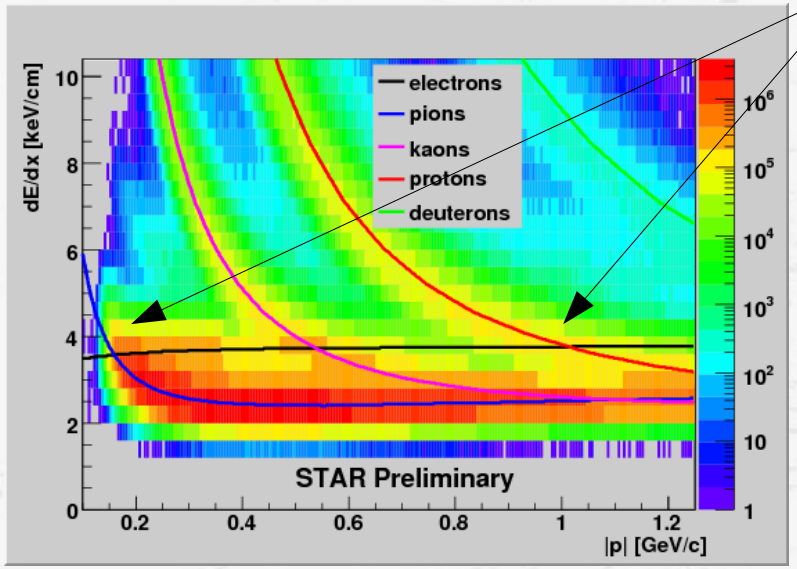
pairs with split tracks

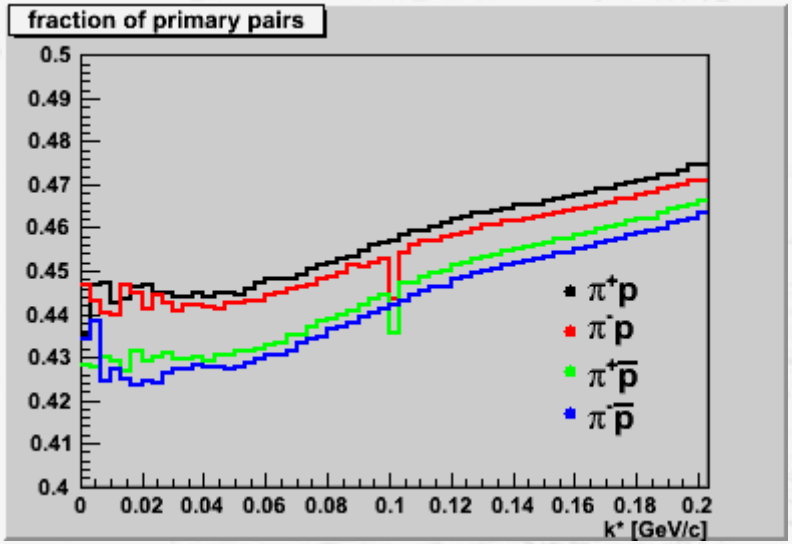
electron-positron pairs from gamma conversion (advanced topological cut)

non π-p pairs based on pair probability



Data analysis





Low relative momentum in PRF corresponds to close relative velocities in CMS.
E.g. pion with p_T=0.1GeV/c has a close velocity proton with p_T=0.67GeV/c. Pion p_T=0.15GeV/c corresponds to proton p_T=1GeV/c. In these regions pions and protons are crossing the electron line.

$$C_{\text{Real}} = C_{\text{Exp}} \cdot C_{\text{Purity}}^{-1}$$

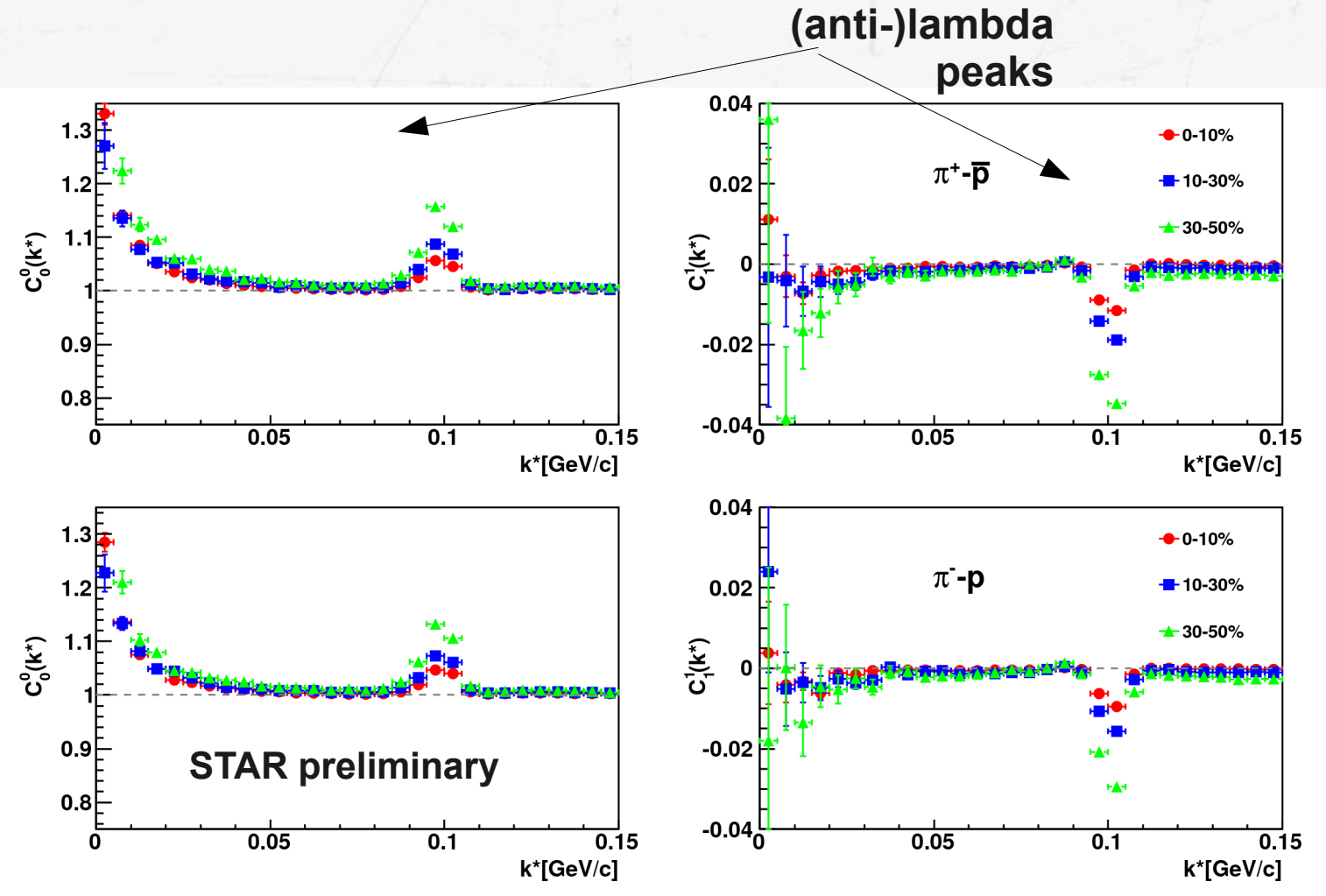
C_{Purity} – two particle distribution weighted with experimental PID probability and fraction of primary pairs

mixed pairs are constructed only from events with similar characteristics:

- z-vertex position 15 bins
- multiplicity 6 bins
- event mean p_T 3 bins

Total 270 bins

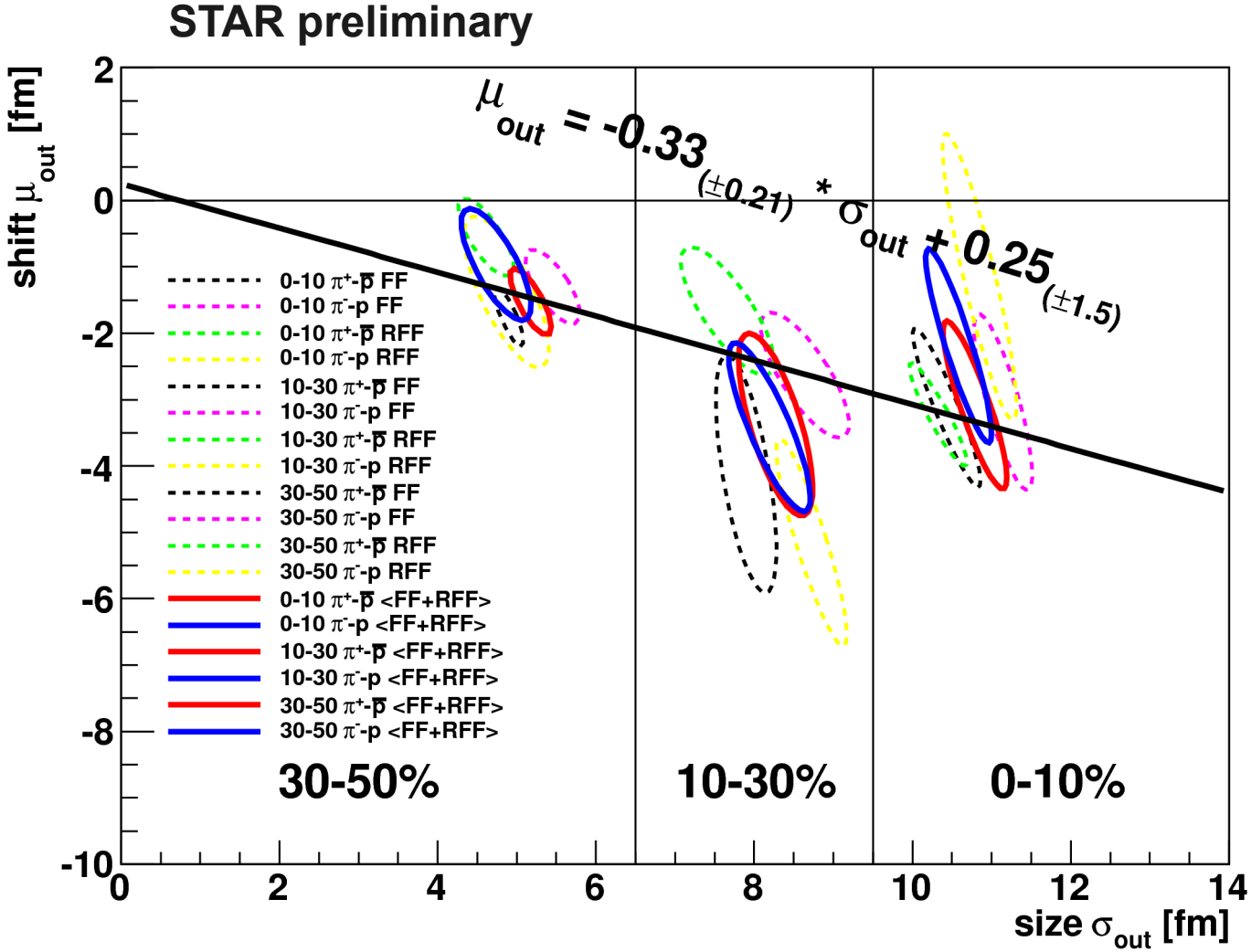
Pion-(anti)proton correlation functions in AuAu at $\sqrt{s_{NN}}$ =200GeV



Lambda peaks do not overlap with femtoscopic correlation effect.

Re C11 at low k* reveals asymmetry between average space-time emission points of pions and protons.

Gaussian 3D fit results LCMS



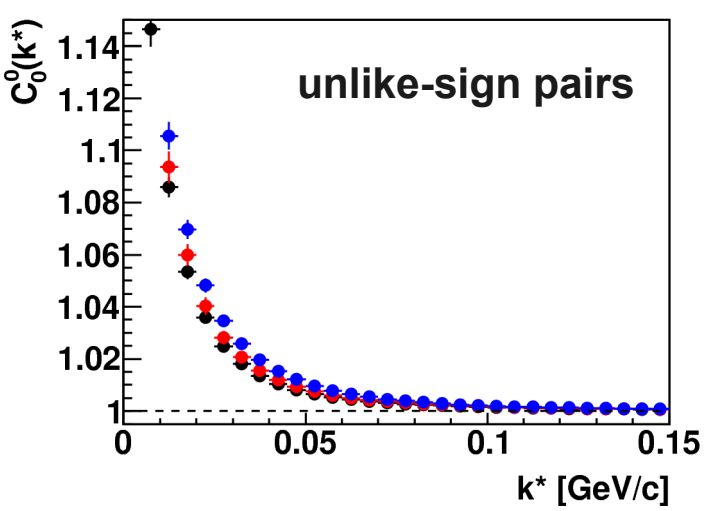
Asymmetry between average emission points of pions and protons and size of the pion-proton source are correlated and depend on centrality.

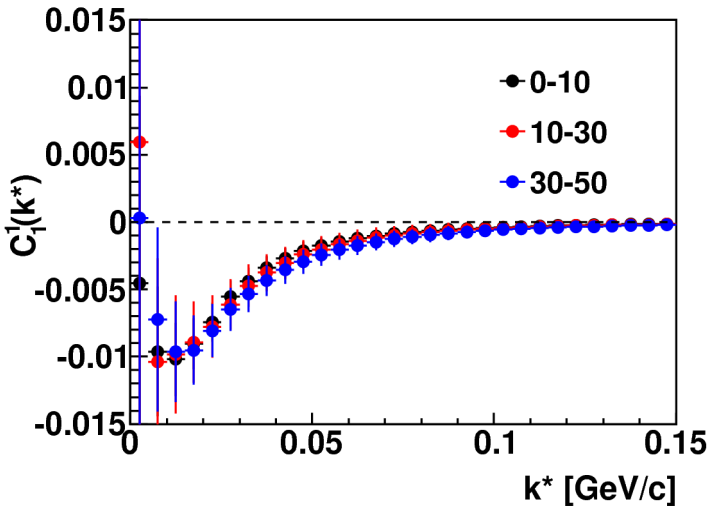
statistical errors only from the fit procedure

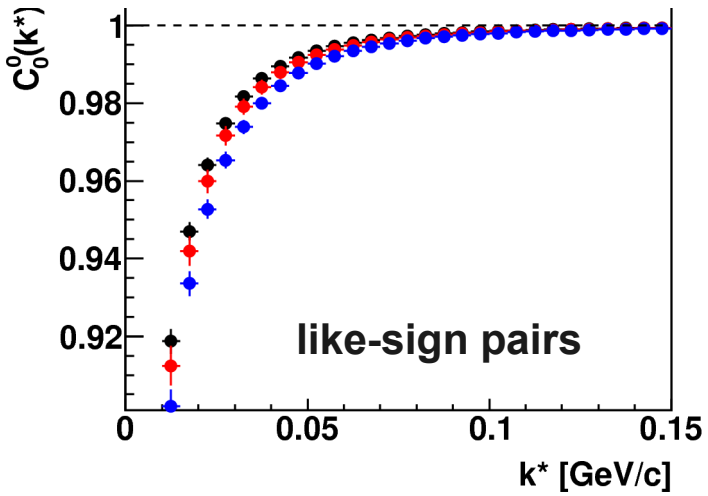
$$\mu_{out} \sim \langle r^* \rangle = \langle \gamma_T (\Delta r - \beta_T \Delta t) \rangle$$

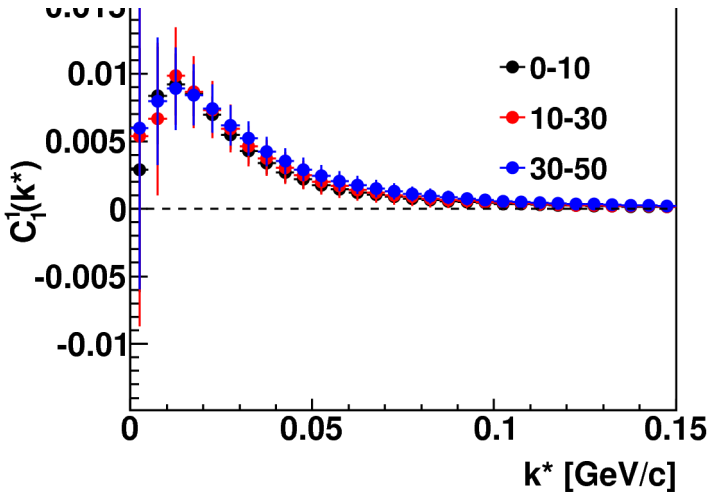
STAR preliminary

Pion-proton correlation functions in Therminator









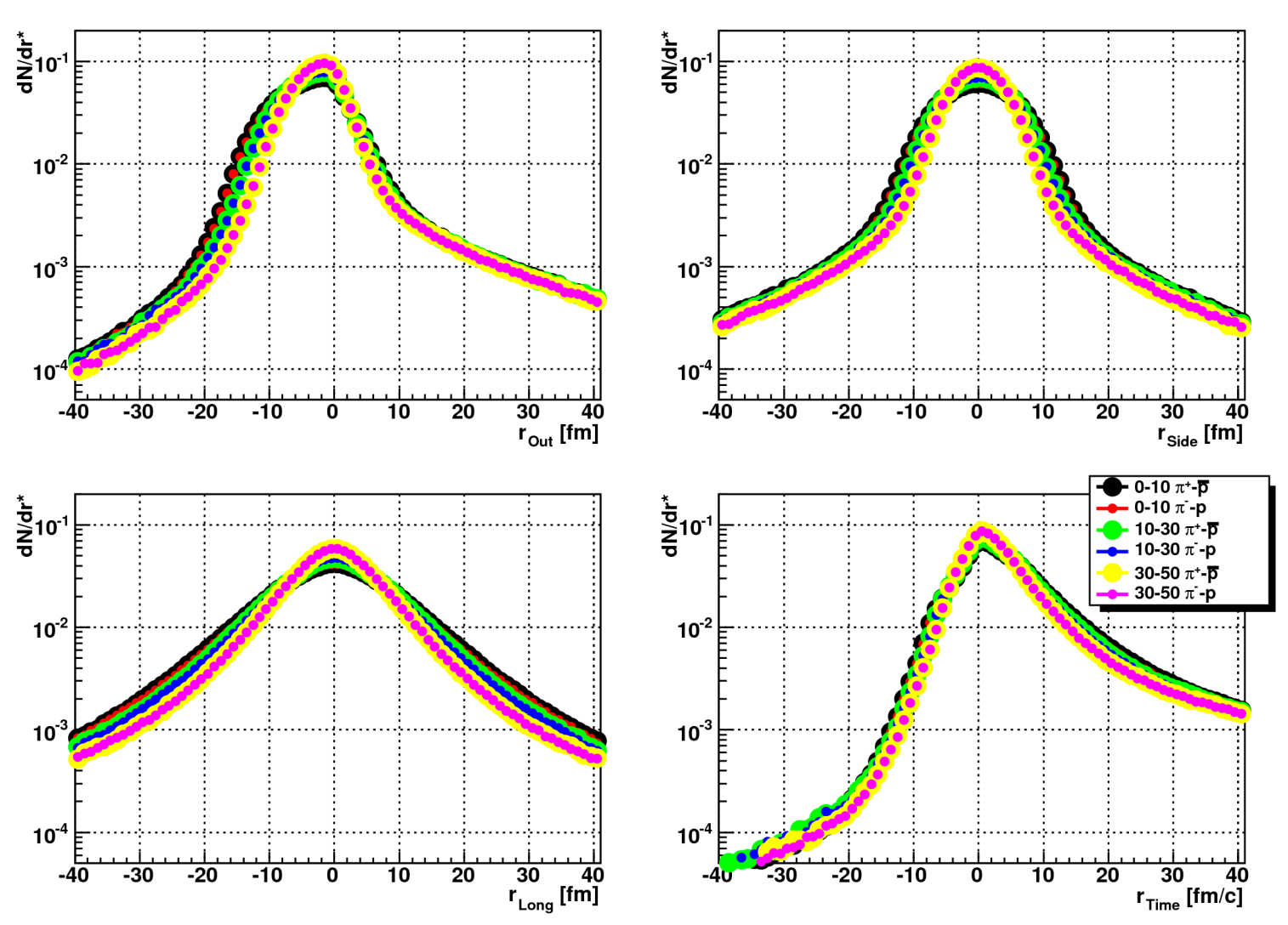
functions show asymmetry

asymmetry may arise from:

- **bulk collective effects**
- **differences in the freeze-out scenario**
- **decays of resonances**

Comp. Phys. Comm. 174 (2006) 669

Two particle pion-proton separation distribution - THERMINATOR



No difference between like-sign pairs and unlike-sign pairs.

Symmetric *side* and *long* components

Non-symmetric distributions in *out* and *time.*

Source profile is non-Gaussian

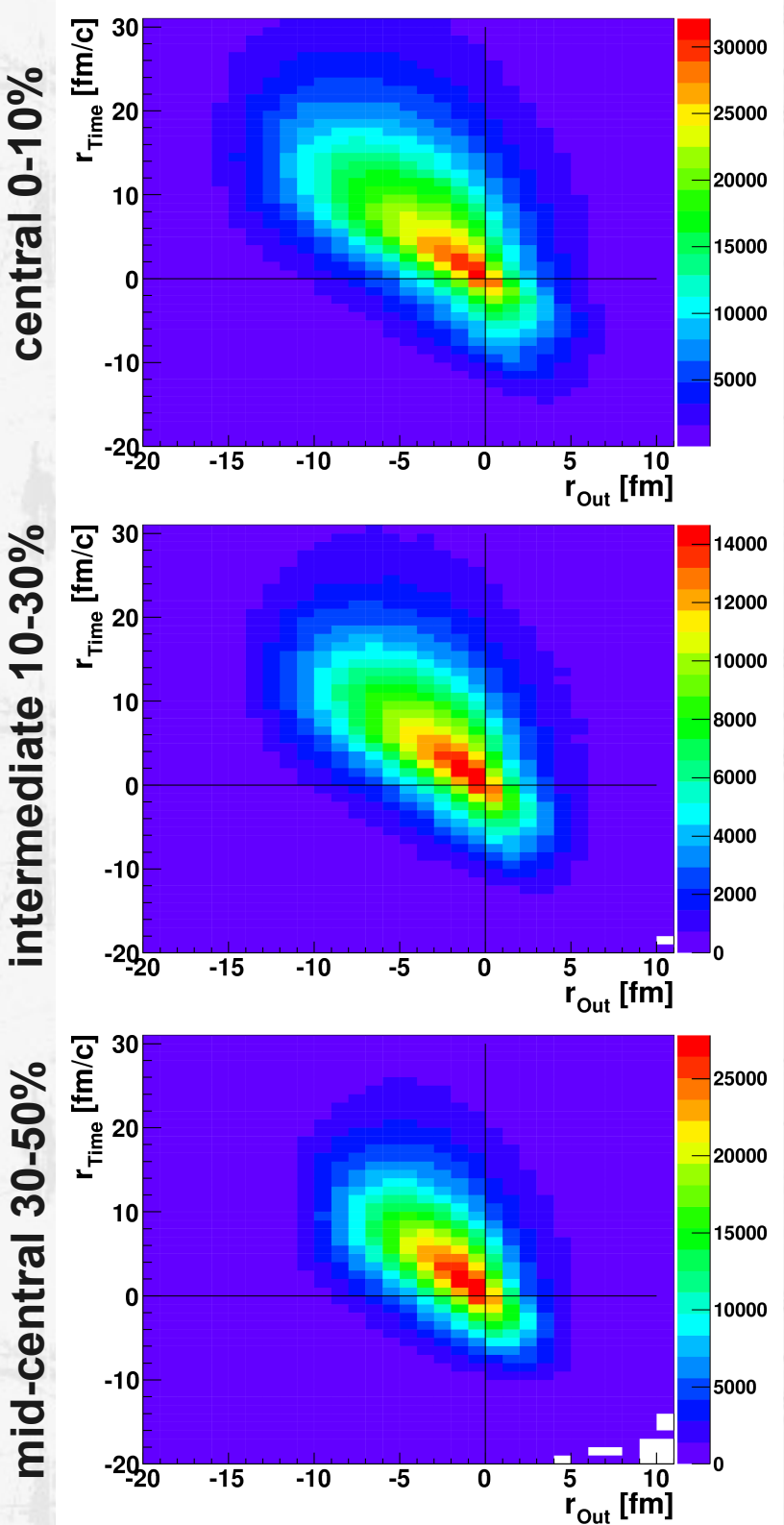
Asymmetries in *out* and *time* components in two particle separation distributions are correlated - Therminator

Positive values of r_{Time} corresponds to pion emitted later than proton.

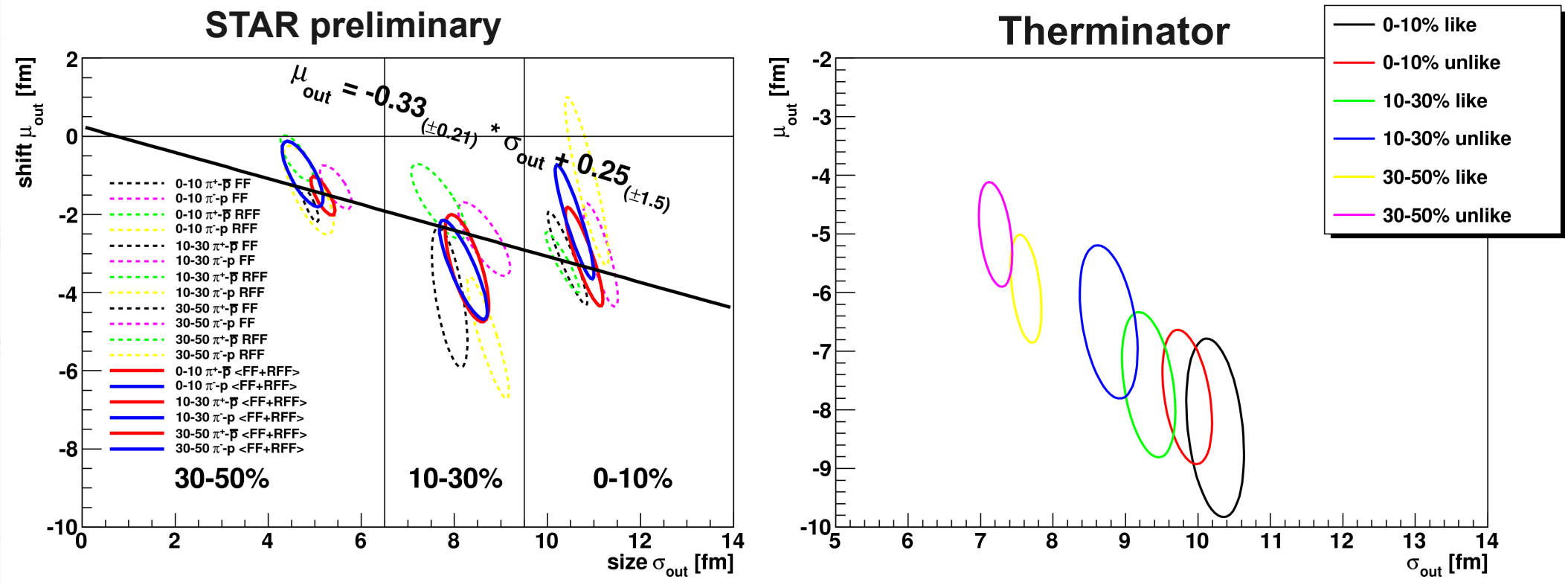
Scenario when pion is emitted earlier than proton is rare.

Bigger difference between emission points of a pion and a proton means bigger difference in emission times – *out-time* correlation

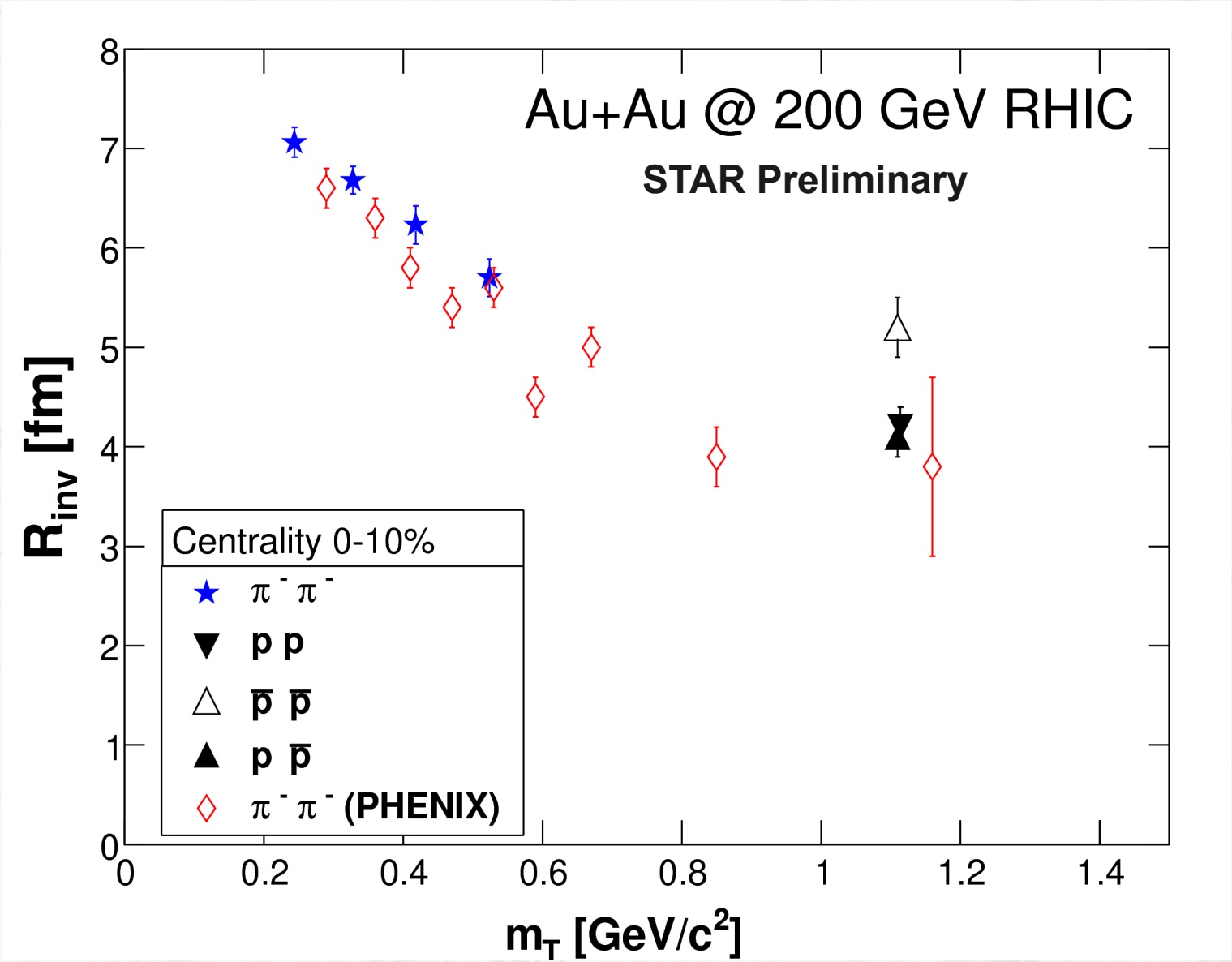
Emission time difference r_{Time} reaches higher values for central collisions than for non-central collisions



Experiment and model ellipses of covariances



Pion & proton HBT



Size of the proton source (black triangles) is smaller than size of the pion source (blue stars / red diamonds)

Conclusions

- We observe space-time asymmetry between average emission points of pions and protons
- Observed asymmetry suggest collective behavior of the created matter
- Space-time asymmetry and size of the π–p source are correlated and depend on centrality
- Size of the proton source is smaller than the size of the pion source
- Asymmetries in *space* and *time* are correlated. In the average, protons are emitted earlier than pions. Average emission point of protons is shifted *outward* in comparison to the average emission point of pions.